Vol. 12, Communication 263. (Fairfield Smith: Use of hydrometers to estimate dry rubber content of latex)

THE JOURNAL OF THE RUBBER RESEARCH INSTITUTE OF MALAYA

IMPERIAL MYCOLOGICAL INSTITUTE

DECEMBER 1947.

Published by
The Rubber Research Institute of Malaya
and printed by
Charles Grenier & Son, Ltd.,
Kuala Lumpur, Malaya.

Edited by C. E. T. Mann on behalf of the Board of the
Rubber Research Institute of Malaya.

Price 50 Cents.

J.R.R.I. Communication 263.

USE OF HYDROMETERS TO ESTIMATE DRY RUBBER CONTENT OF LATEX

BY

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Summary

Metrolacs, Latexometers and Simplexometers are hydrometers, that is instruments which measure the density of a fluid. Owing to the viscosity of latex they cannot be used satisfactorily in undiluted fresh latex, and observations are usually made in latex-water mixtures. The scale heretofore adopted for these instruments to estimate d.r.c. from the observation of density is that appropriate to mixtures of "average" latex of about 35 per cent. d.r.c. with water. The estimate of d.r.c. may be seriously in error when the original latex deviates markedly from the assumed average.

Agreement of factory output with latex weights x Metrolac (etc.) observations gives no check on the reliability of individual readings. The *average* bias of a set of observations (e.g. of tappers' returns) may be adjusted on the basis of factory output; but the amount of rubber brought in by an individual tapper will be over or underestimated by about 3 per cent. for each unit of per cent. d.r.c. by which his original latex as tapped exceeds or is less than the average of the batch.

Variation of temperature, without correction being made for it, will produce errors in estimates of per cent d.r.c. of the fluid observed of 0.3 to 0.7 per °C, depending on whether one is working on the assumption that variation stems from the latex or from varying amounts of added water. In estimating d.r.c. or original latex from 1 : 2 dilutions with water the error will be about 1 per °C, (1.8°F).

Possibilities for improving on the current method of obtaining hydrometric estimates of d.r.c. are discussed.

Hydrometers, usually known on rubber plantations by the names, Metrolac, Latexometer and Simplexometer, are commonly used as the easiest method of obtaining an approximate estimate of the dry rubber content of latex. It is appreciated that they do not in general give accurate results, but the reasons for this do not seem to be understood and there appears to exist much confusion regarding the theory of their use in latex.

Some workers, possibly misled by commercial advertising, appear to think that these instruments measure d.r.c. directly. Therefore it must first be made absolutely clear that a hydrometer is an instrument to measure *density*, which it can do very accurately, but it can measure nothing else.

When it is used for another purpose, e.g. to estimate concentration of sugar in solution, or d.r.c. of latex, this character is inferred from the measurement of density on the basis of a known or supposed relation between density of the fluid and the concentration to be estimated. When an advertisement states ". . . . recording the actual weight of dry rubber . . . . . ." it is to be read as meaning only that the relationship used to convert from the observation of density to the estimate of d.r.c. is incorporated in the scale marked on the hydrometer to eliminate the need for further calculation. To avoid misunderstanding it must be clearly borne in mind that, however the observations may be interpreted, or whatever scale be marked on the hydrometer, the character which is actually measured is density.

When dealing with two pure substances, e.g. sugar and water, there is, at a given temperature, a simple one to one correspondence between concentration and density, and conversion from observation of this to an estimate of that is straight forward. Many workers appear to be under the misapprehension that there is a similar direct relationship between density and d.r.c. of latex-water mixtures. Unfortunately the relationship here is more complex. The purpose of this article is to try to explain the variations which require consideration.

The term " specific gravity " is so often used loosely, without precise definition of the measurement intended, that it appears necessary to begin by defining it precisely.

Specific gravity ($d_{t_1}^{t_2}$) is the ratio of the mass of a certain volume of the substance at a stated temperature t_2 to the mass of and equal volume of a reference substance —usually water—at a stated temperature t_1. Workers on latex almost invariably omit to state the temperature to which their observations refer and this has led to much confusion. Usually the ratio of masses of latex and water, both at the temperature of observation is intended, but this cannot be assumed, and frequently a ratio evaluated for one pair of temperatures has been used in a context requiring a different pair. Lax usage has probably developed because in a temperate climate, owing to the peculiar nature of water whose density changes little between 0 and 15°C, there is, for many practical purposes, little difference in the figures for varying definitions. But above 15°C the changes become important relative to the accuracy required for d.r.c. estimations.

Density is the mass of unit volume of a substance, usually evaluated in c.g.s. units as gram per cubic centimetre or gram per milliliter (1 ml. = 1.000027 c.c.). Since almost all substances expand on heating, density decreases with rising temperature, and therefore here also the temperature of observation, but that one only, requires to be stated. Specific gravity relative to water at 4°C (d_4^t) is equal to density at temperature t expressed as gram per milliliter.*

We shall consider here only density: (1) because it is free from the ambiguities which have become associated with specific gravity; and (2) because, when a hydrometer is used at different temperatures, the corrections for a scale reading d_4^t are much smaller than those required properly to estimate d_t^t , and for small variations of t may often be neglible. This happens because the thermal expansion of fluids is considerably greater than that of solids (cf. recommendations by Stott, 1923, and by the British Standards Institution, 1936).

The density of mixture of two pure substances which mix without chemical interaction is easily determined. Suppose W_r grams of substance r, with volume V_r and density $d_r = W_r/V_r$, be mixed with W_s grams of substance s, with volume V_s and density $d_s = W_s/V_s$. The density of the mixture is clearly

$$d_m = \frac{W_r + W_s}{V_r + V_s}$$

and the weight concentration of r in the mixture is

$$c = \frac{W_r}{W_r + W_s}$$

or the weight: volume concentration (in gm. per ml. or lb.

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* It may be worth while here to note a point often overlooked. For a given latex, per cent. d.r.c. by weight is constant irrespective of temperature; but d.r.c. expressed as weight per volume (gram per 100 milliliter, or lb. per gallon) is not, because with changing temperature the volume alters while the weight does not. The alterations occurring within Malaya are trivial since changes of temperature are small, but it may be relevant when latex is exported to a colder climate. Concentration as weight of rubber per volume of latex = $\frac{\text{weight of rubber x density of latex}}{\text{weight of latex}}$

There seems to be no trustworthy data showing the change in density of latex in passing from 30° to 15°C, but it is probably of the order of .006; therefore the d.r.c. expressed as gm. per 100 ml. or lb. per gal. may be expected on cooling between these temperatures to be increased approximately in the ratio 1 : 1.006.

per gal./10 is $c' = \frac{W_r}{V_r + V_s}$

Combining these, we obtain for the relationship between concentration and density:—

$$\frac{1}{d_m} = \frac{1}{d_s} + \left\{\frac{1}{d_r} - \frac{1}{d_s}\right\} c \quad \ldots \quad (1)$$

$$\text{or} \quad d_m = d_s - \left\{\frac{d_s}{d_r} - 1\right\} c' \quad \ldots \quad (2)$$

The use of hydrometers to evaluate d.r.c. in latex appears to have begun with Eaton's publications, (1912, 1914). The opening sentence of the last cited paper is significant. "Although, in some cases, hydrometers are made with direct readings of the substance to be estimated on the stem, it was thought more desirable in the construction of a hydrometer for the estimation of the rubber content of Hevea latex, to have the instrument graduated in density figures on the stem, and to issue a table with each instrument." He then designed an instrument of particular sensitivity—necessary for this work—with which specific gravities d_{30}^{29} (not densities) can be read to .0002. This instrument later became known as the Latexometer. The table issued with it showed specific gravities and d.r.c's of mixtures of an "average latex" with water. The d.r.c. of the original latex actually used has not been stated in print, but it seems to have been an average of two or three latices with d.r.c. about 35 per cent. The scale adopted is represented by the line FE in fig. 1 for mixtures with water of a latex of 34.62 g. p. 100 ml. and density .9753; i.e. the line corresponding to equation (2) for mixtures of one substance (latex) of density .9753 with another substance (water) of density .9960. It was never claimed, and it may be doubted if it was ever intended, that the scale should be used to estimate d.r.c's of widely different original latices. At the time it was introduced the principal problems to be dealt with were: detection of dilution of latex by tappers, and dilution to a standard for coagulation. *Assuming* that the density and d.r.c. of the original latex as it came from the tree was generally close to the adopted figure (which may have been nearly enough true when seedling rubber was universal) the scale was well adapted for these purposes. Although the wording of early papers was sometimes ambiguous, it is in general clear that the originators appreciated the limited abilities of the new instrument and

how it should be used. For example Eaton (1914) p. 316 writes ". . . . the method recommended . . . . allows the latex to be reduced always to a standard density . . . . ." Note: " standard density ", not " standard d.r.c." But in later days, when increased variation of tapping systems and of clones has increased the range of d.r.c's in natural latex, their use has been strained to meet a wider range of conditions and purposes. Success in practice, and the general appearance of reasonable agreement between estimates of crop based on hydrometric determinations of d.r.c. and actual factory output, undoubtedly derives from the condition that in general the average d.r.c. of estate latex still approximates to 35 per cent. But agreement between factory output and quantities of latex multiplied by hydrometer readings for a month's crop is no test of the accuracy of individual hydrometric estimates, since equally good agreement would be given by multiplying all latex weights by the average d.r.c. Our correspondence suggests that more obvious disagreements are becoming frequent.

The Metrolac and Simplexometer are based on precisely the same scale, the only difference (apart from shapes of the instruments and ranges of values covered) being that the Metrolac is marked with estimates of d.r.c. as given by Eaton's tables; and the Simplexometer is marked with arbitrary numbers intended to simplify readings on the instrument.

Today, with wider variation of d.r.c. resulting from different clones and tapping systems, it cannot in general be assumed that all latex comes from the tree with d.r.c. and density approximately equal to that used to determine the Eaton scale, and that observed variations therefrom are due to admixture with water.

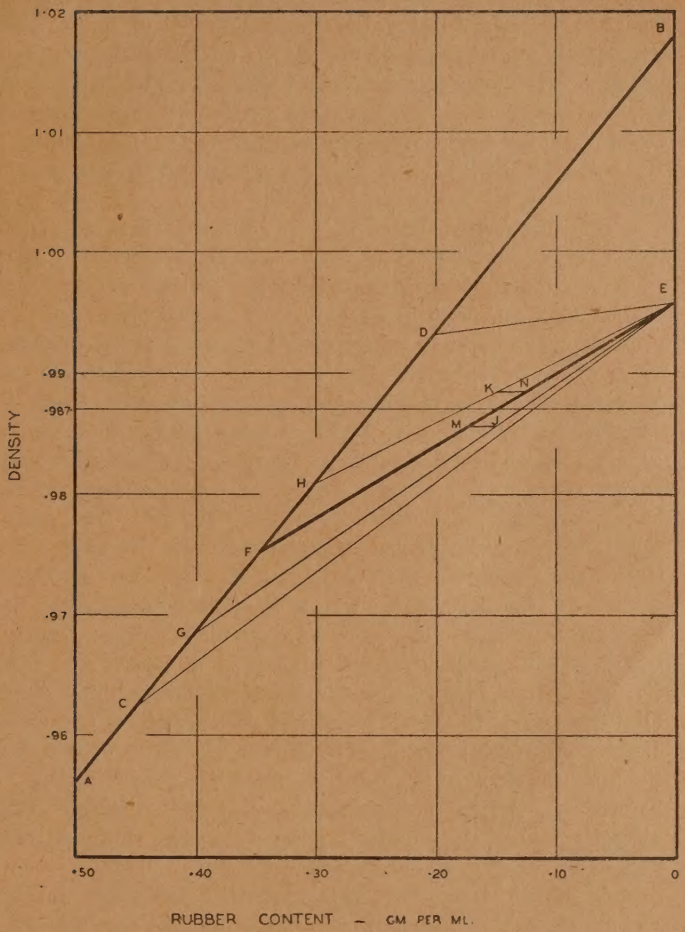
The relation between d.r.c. and density of undiluted fresh latex can be determined from equations (1) or (2) if we know the density of the rubber phase and of the serum. The initial step to develop a logical system of hydrometry in relation to latex is therefore to consider these characters.

Firstly the density of the rubber particles in latex is not precisely known; and it varies with what we choose to define as rubber. Available evidence indicates that the density of purified rubber at 29°C is about .902 to .9035. But for what may be termed " crude rubber " containing such serum substances as are usually included with it in ordinary determination of d.r.c. by coagulation, collation of available evidence (Smith, 1940) indicates d (29°C) = .906. This

difficulty is common to any method of determining d.r.c., slightly different results being given depending on the amount of dilution before coagulating and on the thoroughness of washing the coagulum. Further, observations by de Vries (1919) on normal latex, and by Van Gils (1939) on purified centrifugal concentrates, both suggest that density of rubber may increase with decreasing d.r.c. of the parent latex, presumably due to adsorption of more serum solids. In both investigations however the density of the rubber phase was estimated indirectly. No data appear to be available showing correlation of densities of normally prepared rubbers with the d.r.c's of the latices from which they were coagulated. However, for our present purpose, the problem of determining the true density of rubber particles in latex may be avoided by deriving a conversion scale directly from correlation of observed densities and coagulated d.r.c's under defined conditions. A scale so derived will incorporate within itself any systematic variation in densities of rubbers coagulated from latices of varying d.r.c's; but this is as it should be for the purpose of estimating the yield of coagulated crude rubber, as is usually wanted in practice. Although it may be convenient, for adjustment to varying circumstances, to associate a specific value of d_r with such a scale, it should be recognised that this is to be taken only as an empirical value for the purposes in hand, and not as an unbiased estimate of the true density of rubber.

Secondly, the serum in latex is not a single substance like water, but is a solution of mixed ingredients —proteins and salts; and unfortunately there is no satisfactory evidence yet available to show how its density varies between different estates, clones, seasons etc. Rhodes (1934) reported a series of observations on specific gravities of latices from nine estates, but the detailed data were lost by fire and the extant summary leaves no more than a hint that one of the estates may have been producing a serum significantly different in density from the others. However, available evidence suggests that serum density is not correlated with d.r.c. of latex,* that the average density (at 29°) is about 1.018, and that this value may permit estimates of d.r.c. sufficiently accurate for some purposes. As noted above for d_r it may be convenient to base the conversion scale on a merely empricial estimate of d_s.

* But since this paper was written we have received a latex of 25 per cent: d.r.c. with serum which seems to be much nearer than usual to the density of water...Whether or not this may be a common feature of low d.r.c. latex is unknown.



Thirdly, and this raises the main complications in applying hydrometry to d.r.c. estimation, latex as it comes from the tree is usually too viscous to permit a hydrometer to float freely in it, an essential condition to obtain a satisfactory reading. It is therefore usually necessary to add water before using the hydrometer. We then obtain mixtures of three substances, each of different density and in varying quantities, and this destroys the one to one relationship between density and concentration of rubber in the consequent rubber-serum-water mixtures.

Assume meantime that the rubber phase may have a constant density (at 29°C) of .906, and that the density of

fresh serum is stable at 1.018. The density of latex coming from the tree should then lie on the line AB of fig. 1; and the density of mixtures of any given latex with water will lie on a line connecting the point on AB representing that latex to the point E. It can thus be seen that mixtures of water with latices varying originally from 20 to 45 gm. per 100 ml. (2 to 4.5 lb. per gall.) may fall anywhere in the triangle CDE*.

The range of variation in d.r.c. for a given density, or *vice versa*, is considerable. For example at density .987, which corresponds to a reading marked 1.5 lb. per gall. on a Metrolac (the point frequently used to determine dilution prior to coagulation in a factory), the figure shows that the d.r.c. of the mixture may vary from 25 to 12 gm. per 100 ml. Such variation is in fact observed (cf. Bishop, 1932, Table I, and Smith, 1940, p. 235, which shows variation from 12 to 16 gm. per 100 ml.). Mixtures having d.r.c. greater than 18 per cent. at this density are to be expected from latices having originally less than 30 gm. per 100 ml. The figure shows that as the latex point moves from H toward D, latex-water mixtures with density .987 (i.e. at the intersection of the line from the latex point to E with the horizontal line d = .987) have d.r.c's which increase rapidly, till at 25 gm. per 100 ml. no dilution at all would be called for, and beyond that the specific mixture is impossible. Such mixtures tend to be too viscous to permit satisfactory observations with hydrometers. Hence it seems probable that the practice of diluting to a standard hydrometric density before coagulating has worked fairly well because high viscosity makes the method unusuable in the comparatively rare cases when it would become seriously in error.

As already noted the scale used with metrolacs, latexometers and simplexometers is represented by the line FE, which represents mixtures with water of a latex having initially d.r.c. 34.62 g.p. 100 ml. and density .9753. As this scale is commonly used to control tappers' production, and sometimes also to determine their remuneration, it is relevant to consider what happens when the original latex obtained by a tapper differs from the assumed standard.

For example: suppose two tappers each bring in 1.5 lb. of dry rubber, but A obtained his as 3/8 gallon of original

* Similar diagrams—based on older figures, since revised—were presented by de Vries in Fig. 1 and 4 of his book "Estate Rubber" (1920) which contains also a good account of the use of hydrometers in estate practice.

latex at d.r.c. 4 lb. per gallon, while B obtained his as ½ gallon at d.r.c. 3 lb. per gallon. Suppose, following a common system, that the latex of each is diluted with water to a total volume of 1 gallon and then tested by hydrometer. Each mixture is in reality at a d.r.c. of 1.5 lb. per gallon. A's latex when mixed with water has moved along the line GE, and the gallon mixture is at J with d = .9857, which is assessed by metrolac or simplexometer as if it were on FE at M, indicating 1.71 lb. rubber in the gallon. B's mixture on the other hand would be on line HE at K with d = .9885, and would be assessed as being at N with 1.25 lb. in the gallon. Precisely similar results would be given by a fixed dilution (e.g. 1 latex : 1 water) and multiplying up by the appropriate factor.

More generally, if a latex-water mixture be assessed on the assumption that it has come from the tree with c gm. rubber per ml. and density d_l, whereas it has in fact $(c + x)$ gm. per ml., then the ratio of $\frac{\text{hydrometer assessment}}{\text{true assessment}}$ is independent of the amount of water and is given approximately by

$$1 + abx - ab^2x^2 + \ldots\ldots\ldots$$

where* $a = \dfrac{d_s - d_w}{d_w - d_l}$, $b = \dfrac{d_s - d_r}{d_r\,(d_s - d_l)}$

For the Eaton scale at 29°C with c = .346, d_l = .9753, d_w = .9960, and assuming d_s = 1.0179, d_r = .9063 the ratio is

$$1 + 3.06x - 8.84x^2 + \ldots\ldots\ldots \qquad (3)$$

When x is less than .03 (3 in per cent. d.r.c.) x^2, as well as higher powers, may be ignored; and the formula means that for every one in per cent. d.r.c. that latex from the tree exceeds or falls below 35 per cent., a tapper's yield would be over or under assessed by approxiamtely 3 per cent. of the weight of rubber actually brought in. (*cf.* The example above: x = + .05 led to an assessment of 1.71 in place of the true value of 1.5, an excess of 14 per cent.; x = − .05 led to 1.25, a deficiency of 17 per cent.; both as given by (3) using the quadratic term, and close to 15 per cent. as given by the first term only).

Possibilities for improvement in the estimation of d.r.c. from hydrometric observations.—It is evident that a hydrometer reading alone cannot give accurate estimates of d.r.c. of latex-water mixtures in general. Besides temperature (see

* d_r =density of rubber, d_s = density of serm, d_w = density of water.

below) information on one other variable, either the density and d.r.c. of the original latex or the amount of water added, must be known.

This means further that no single conversion scale, which could be incorporated in the calibrations of a hydrometer, will serve to give reliable estimates over the range of conditions to be met in practice. If it is desired to seek a method of obtaining greater accuracy in estimates of d.r.c. from hydrometric observations the only practicable procedure appears to be to use a standard type of instrument (preferably graduated to indicate densities, the one thing that the instrument can accurately measure) and interpret the observations by means of a table adapted to the special circumstances of the moment. This course has been forced on one after another of the applications to which hydrometry has been put. (cf. British Standards Institution, 1936, and Stott, 1923. A quotation from the latter has been given in Comm. 244, p. 238). Since application to latexometry is more complicated than in most other fields of application, it seems inevitable that the same procedure must eventually be adopted here also.

Reasonably accurate assessment of dry rubber contents could then be obtained under two sets of circumstances; but when these are mixed, as they very frequently are, there seems no way of eliminating the potential variation indicated by the triangle CDE of figure 1.

I. If it can be assured that the latex reaches the measuring shed *undiluted*, one could observe the density of a mixture made from measured volumes of latex and of water; and to estimate d.r.c. would refer to a table prepared on the assumption that quantity of water is known. Unfortunately however, if the latex received had previously been diluted with water, the total weight of dry rubber would be overestimated by

$$\frac{d_r\,(\,d_s\,-\,d_w}{d_s\,-\,d_r} = .179 \text{ times the weight of water added.}$$

At first sight it may seem surprising that the error is independent of actual d.r.c. of the latex, but it has a simple explanation. The density of latex of 17.9 per cent. by weight is equal to that of water; therefore addition of water affects the density of a mixture in just the same way as would additions of 17.9 per cent. latex. (Eaton, 1912, and de Vries, 1920, note that effects on viscosity would be different; but observation of viscosity is not meantime considered practicable as a field test for amounts of dilution).

Accuracy attainable by this method depends, in addition to confidence in the absence of prior dilution, on how accurately the line AB of figure 1 represents the true relationship between d.r.c. and density of original latices at a given time and place. In Rhodes' data the overall standard deviation of single observations of per cent. d.r.c. for given density was about 3—not a cheering figure. However his data are distinctly heterogeneous and contain indications that within individual estates the standard deviation may have been less than 1. De Vries' observations on latex from more restricted fields showed a standard deviation of about 0.6. Against this Rhodes' data for one small holding over 14 months (Comm. 244, sec. IV) again showed a standard deviation of 3. Considering the proven seasonal variation in composition of serum (Wiltshire, 1934) considerable variation in density must also be anticipated and seems to afford a reasonable explanation. Possibly much of the variation in all of the above observations may have been due to temperature (see below). Therefore, although it seems likely that a fixed average table may frequently give estimates of d.r.c. appreciably in error, with appropriate choice of table for restricted regions and seasons, and adjustment for temperature, reasonable accuracy might be attained. The determination of regions and periods for which a single table would serve requires many more observations than are at present available on the variation of density with d.r.c. The regions of applicability of each table would undoubtedly be much greater than the regions envisaged under method II below, and although the preparation of each would be more troublesome it is likely that three or four might suffice to cover variants of the line AB.

II. On the supposition that latex leaves the tree with approximately the same d.r.c. and density, at least on the average of each task over several days, and that differences observed are due principally to contamination with water, tables could be drawn up to show variation of density and d.r.c. for known latices mixed with varying amounts of water. The scale on which present instruments are based is an instance of such a scale for a latex of 35 per cent. d.r.c.

If for appreciable areas and periods of time variations of d.r.c. of initial latex are not great, it might be practicable to use a scale selected for given circumstances; or else to adjust a batch of observations according to a separately determined average d.r.c. for the batch. It is therefore relevant to enquire what may be the variation within

groups of tasks on similar trees. Available evidence (Rhodes, 1939; Wiltshire, 1934; Grantham, 1922; tapping experiments, unpublished) indicates for fields of 16 to 80 tasks standard deviations of d.r.c. as follows:—

random variation	about .6
between days within a month	,, 1 to 2.5
between tasks	,, .7 to 1.4

If we take the view that it does not much matter if a tapper be penalised one day and rewarded another provided his average is about correct, variation between tasks is of principal interest. Suppose for the sake of argument that standard deviation of per cent. d.r.c. between tasks is 1. This means that about 30% of tappers would get latex differing from the average per cent. d.r.c. by more than one, and (*cf.* equation (3) above) would be credited with over 3 per cent. more or less rubber than they actually brought in; about 5% of tappers would get latex differing by more than 2 in per cent. d.r.c., and a bonus or penalty of more than 6 per cent. of their true yield. Assessment of tappers by this method therefore penalises tappers working on trees yielding latex of low d.r.c., and those who by tapping deep get a greater yield at lower d.r.c.; and *vice versa*. (Wiltshire, 1934, and Eaton and Fullerton, 1929, show deep tapping yielding on average latex with per cent. d.r.c. lower than that from shallow tapping by $1.66 \pm .29$).

Temperature was neither controlled nor recorded in detail for the observations discussed above. Temperature affects the problem in two ways. Firstly owing to thermal expansion of the hydrometer the instrument readings will give the true density only at the temperature for which the instrument has been graduated—(for standard British hydrometers 20°C, for latexometers—reading specific gravity—29°C). However knowing the thermal expansion of the hydrometers, and the temperature of the fluid observed, it is a fairly simple matter to apply an appropriate correction. As indicated above for a hydrometer graduated to read densities (not specific gravities) this is a trival correction which would not generally be required for the variation of temperatures met with in Malaya. The error of using in the tropics an instrument graduated for 20°C can be incorporated in the conversion table. Secondly, the density of latex varies with the temperature, and the amount of variation varies with its d.r.c. The thermal expansivity of latex calls for further investigation, but for normal ranges of d.r.c. and Malayan temperatures the change in density per degree C may be

taken as .0004. The alteration in density of latex-water mixtures with alteration of d.r.c. depends on the way in which the variation is produced. Working at a fixed dilution with different original latices, the change of density per unit of per cent. d.r.c. of the mixtures is about .0012. Consequently if no correction for temperature is applied, an estimate of per cent. d.r.c. of the mixture will be in error by .33 per °C deviation from the temperature for which the d.r.c.: density scale was designed; or an error of 1 per °C in estimating per cent. d.r.c. of the latex from 1:2 latex-water mixtures. Working with a given latex of c per cent. d.r.c. and variable amounts of water, the change of density for one per cent. d.r.c. of the mixture will be about .00123-.0219/c, or about .0006 for latex of 35 per cent. d.r.c. Therefore in this case the errors in estimating per cent. d.r.c. without temperature correction will be about .66 per °C.

One other factor merits attention—*surface tension*; but there appears to be not yet available sufficient data on variation of surface tension in latex-water mixtures to merit discussion here. It is principally of concern to the manufacturer in graduating hydrometers for use in a given type of fluid. It is unlikely to be of practical importance to the user, except to explain the importance of keeping clean both the hydrometer and the surface of a fluid under observation. Distortion of the meniscus owing to dirt on the hydrometer stem or on the surface of the fluid may produce errors greater than .001 in observation of density. Therefore before use hydrometers should be carefully cleaned with soap and water, and thoroughly rinsed with clean water.

Conclusions with respect to hydrometric control of tappers' produce: If tappers bring in undiluted latex, which is then mixed with a measured quantity of water at known temperature, moderately accurate estimates of d.r.c. may be deduced from a hydrometer reading. The chief remaining source of error would be variation in density of sera. It might be practicable to draw up a series of tables for specified circumstances, but at present there is little evidence to indicate how much serum density may vary between fields or clones on one estate, between estates, and between seasons; and thence whether such procedure will be necessary or practicable.

If latex as brought for measuring contain unknown amounts of water, and nothing definite is known about its origin, it is difficult to suggest how procedure can be improved. Although average bias may be removed by com-

parison with factory output, this does nothing to remove errors as between one tapper and another.

Current methods over or underassess individual tappers' yields by about 3 per cent. for each one in per cent. d.r.c. that their initial latex exceeds or is less than the average. Where planting material is all similar with respect to age and clone, on average over a period of time about 5 per cent. of tappers might get a bonus or penalty of greater than 6 per cent. of their true yields, while probably about 70 per cent. would be assessed within 3 per cent. of the correct amounts. On individual days the figures would probably be 70 per cent. of tappers within ± 6 per cent., and 5 per cent. with errors greater than 12 per cent. The method does give rough control of dilution with water, but on an estate with a wide range of clones and ages where field d.r.c's may range from 30 to 40 per cent., and the only control comes from total yield over all, the error inflicted on whole groups of tappers may approach 20 per cent.

Deep tapping may be penalised, possibly to the extent of 4 or 5 per cent as between the deepest and shallowest tappers, although probably only few would reach these limits.

Tappers whose latex becomes warmer by standing in the sun may have their apparent yield increased by 1.5 to 2 per cent for each °C by which the temperature of their latex exceeds that of their fellow workers.*

These considerations suggest that, when payment of individual tappers is made on the amount of rubber harvested, it is advisable to evaluate d.r.c. by coagulation, as is done on many estates.

ACKNOWLEDGEMENT

I am greatly indebted to Mr. J. D. Hastings for discussion and criticisms which have contributed substantially to the final form of this paper.

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* The water used for dilution will of course reduce temperature differences of the fluids actually observed, but this will be almost exactly counter balanced by the increased quantity of fluid by which the error stands to be multiplied.

Throughout the above discussion some danger of ambiguity is created by the unit of d.r.c. being per cent. of latex. An attempt has been made to avoid this by speaking of variations in per cent. d.r.c., as contrasted with statements about errors proportional to the character under consideration. For example in this discussion of temperature, a rise of temperature by 1°C in latex of 35 per cent. d.r.c. would decrease density by .00043, leading to an apparent increase of 0.7 in per cent. d.r.c. $= \frac{0.7 \times 100}{35}$ = 2 per cent. of the yield of rubber.

Literature Cited

BISHOP, R. O. (1932). *R.R.I.M. Manual No.* 3.

BRITISH STANDARDS INSTITUTION (1936). *British Stand. Spec. No. 718-1936.*

EATON, B. (1912). *F.M.S. Dept. Agric. Bul.* 17.

EATON, B. (1914). *Agri. Bul. of F.M.S. 2*:225—230 and 314—322.

EATON, B. AND FULLERTON, R. G. (1929). *J.R.R.I.M. 1*:132—134.

VAN GILS, G. E. (1939). *Arch. v.d. Rub. Culture 23*:130—139.

GRANTHAM, (1922). *Arch. v.d. Rub. Cult. 6*:484.

RHODES, *E.* (1934). *J.R.R.I.M. 5*:234—250.

RHODES, E. (1939). *J.R.R.I.M. 9*:126—141 (Comm. 238).

SMITH, H. FAIRFIELD, (1940). *J.R.R.I.M. 9*:218—124 (Comm. 244).

STOTT, V. (1923). *Dictionary of Applied Physics 3*:431—444.

DE VRIES, O. (1919). *Arch. v.d. Rub. Cult. 3*:183—206.

DE VRIES, O. (1919). *Arch. v.d. Rub. Cult. 3*:183—206.

DE VRIES, O. (1920). *Estate Rubber*: Batavia.

WILTSHIRE, J. L. (1934). *R.R.I.M. Bul.* 5.